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Title:
IEC 60034-31: Rotating electrical machines - Part 31: Guide for the selection and application of energy-efficient motors including variable-speed applications

(Titre) :

Introductory note

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ROTATING ELECTRICAL MACHINES

Part 31: Guide for the selection and application of energy-efficient motors including variable-speed applications

FOREWORD

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- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- The subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 60034-31, which is a technical specification, has been prepared by IEC technical committee 2: Rotating machinery.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
XX/XX/DTS	XX/XX/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date[1)] indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

1) The National Committees are requested to note that for this publication the maintenance result date is 2013

INTRODUCTION

The present document gives technical guidelines for the application of energy-efficient motors in constant-speed and variable-speed applications. It does not cover aspects of a pure commercial nature.

Standards developed by IEC/TC 2 do not deal with methods of how to obtain a high efficiency but with tests to verify the guaranteed value. IEC 60034-2-1 is the most important standard for this purpose.

For approximately 15 years regional agreements were negotiated in many areas of the world regarding efficiency classes of three-phase, cage-induction motors with outputs up to about 200 kW maximum, as motors of this size are installed in high quantities and are for the most part produced in series production. The design of these motors is often driven by the market demand for low investment cost, hence energy efficiency was not a top priority.

In IEC 60034-30 IE efficiency classes for single-speed cage-induction motors have been defined and test procedures specified:

IE1	Standard-Efficiency
IE2	High-Efficiency
IE3	Premium-Efficiency
IE4	Super-Premium-Efficiency

Determination of efficiency for motors powered by a frequency converter will be included in IEC standard 60034-2-3.

However, for motors rated 1 MW and above, which are usually custom-made, a high efficiency has always been one of the most important design goals. The full-load efficiency of these machines typically ranges between 95 and 98%. Efficiency is usually part of the purchase contract and is penalized if the guaranteed values are not met.

With permission from NEMA, some parts of this TS are based on NEMA MG 10, “Energy Management Guide For Selection and Use of Fixed Frequency Medium AC Squirrel-Cage Polyphase Induction Motors”.

ROTATING ELECTRICAL MACHINES

Part 31: Guide for the selection and application of energy-efficient motors including variable-speed applications

1 Scope

This part of IEC 60034 provides a guideline of technical aspects for the application of energy-efficient, three-phase, electric motors. It not only applies to motor-manufacturers, OEMs (original equipment manufacturers), end-users, regulators, legislators but to all other interested parties.

This guide is applicable to all electrical machines covered by IEC 60034-30. Most of the information however is also relevant for cage-induction machines with output powers exceeding 1 MW.

2 References

The following referenced document is indispensable for the application of this document.

IEC 60034-30, *Rotating electrical machines — Part 30: Efficiency classes of single-speed three-phase cage induction motors (IE-code)*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60034-1 and the following apply.

Brake motor
A motor equipped with an electro-mechanical brake unit mounted directly on the motor shaft without couplings.

Geared motor
A motor directly attached to a gearbox without couplings (i.e. the first gear wheel is fixed to or integral with the motor shaft).

Nominal efficiency
The efficiency value required in order to meet a certain efficiency class according to the IE efficiency tables.

Average efficiency
The average of efficiency values for a population of devices of the same design and rating.

Minimum efficiency
The rated efficiency as declared by the manufacturer minus the tolerance according to IEC 60034-1. This efficiency value is guaranteed by the manufacturer for any given individual motor of a large population.

Rated efficiency
The efficiency value assigned by the manufacturer, equal or higher than the nominal efficiency of the rated efficiency class .

3.2 Symbols

η_n is the nominal efficiency, %

η_N is the rated efficiency, %

f_N is the rated frequency, Hz

n_N is the rated speed, min^{-1}

P_N is the rated output power, kW

U_N is the rated voltage, V

4 General

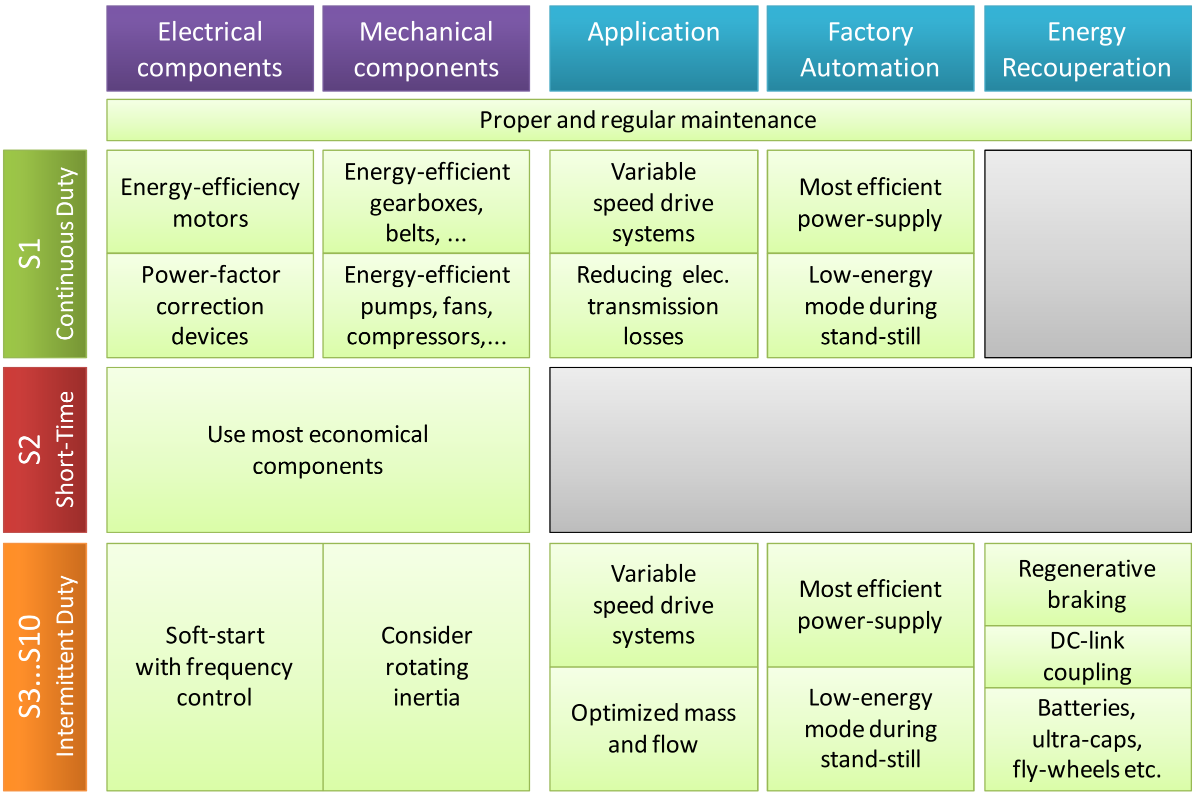

Figure 1 Overview of different areas for savings of electrical energy with drive systems

Energy can be saved in different areas of electrical drive systems depending on the duty type (continuous or intermittent).

In continuous duty applications, improved efficiency of the electrical motor is beneficial. An improved power factor (frequency-converter, synchronous motor) can help reduce I^2R losses in cables. Mechanical optimizations (gearbox, belts, pumps, fans etc.) may lead to much greater savings than improvements of the electrical motor. The application must be regarded as well. Proper maintenance and demand oriented speed control are often helpful.

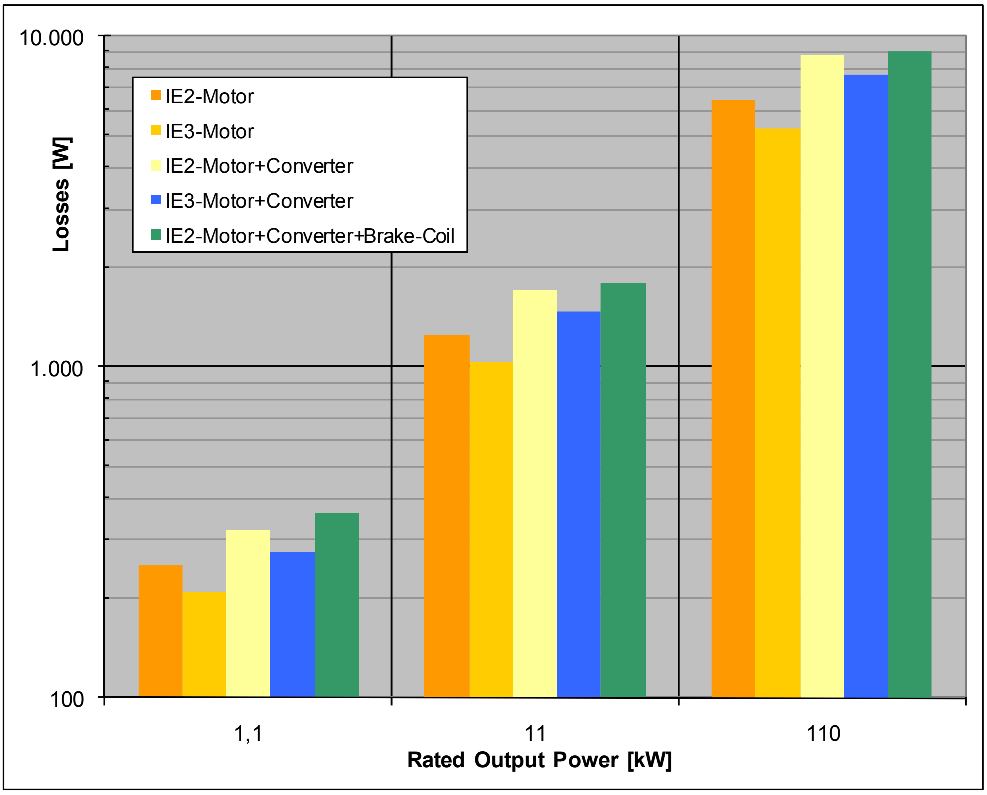

Figure 2 Typical losses of energy-efficient motors, converters and electro-mechanical brakes

Figure 2 gives an overview of typical losses of energy saving motors, voltage-source frequency converters and brake coils of electro-mechanical motor brakes.

Many industrial plants already have a high energy consumption of the low voltage control circuits (typically 24V power supply). Therefore, high-efficiency low-voltage power supplies should be used. If possible, the factory should be shut down during long standstill periods (weekends, holidays).

In intermittent-duty applications, high-efficiency electrical motors are not very useful and may even use more energy due to their increased inertia and start-up currents. For these applications, the energy consumption during the starting phase can be reduced by ramping with a frequency-converter. Intermediate energy storage may be beneficial when the operating cycle includes frequent regenerative phases (for example hoist drives, lifts, cranes etc.).

5 Efficiency

Motor efficiency is a measure of the effectiveness with which electrical energy is converted to mechanical energy, and is expressed as the ratio of power output to power input:

$$Efficiency = \frac{OutputPower}{InputPower} = \frac{OutputPower}{OutputPower + Losses}$$

Motor efficiencies are usually given for rated load, although 3/4 load and 1/2 load may also be provided.

The efficiency of a motor is primarily a function of load, rated power, and speed, as indicated below:

a) A change in efficiency as a function of load is an inherent characteristic of motors. Operation of the motor at loads substantially different from rated load may result in a change in motor efficiency (see Fig. 3).
b) Generally, the full-load efficiency of motors increases with physical size and rated output of motors.
c) For the same power rating, motors with higher speeds generally, but not always, have a higher efficiency at rated load than motors with lower rated speeds. This does not imply, however, that all apparatus should be driven by high-speed motors. Where speed-changing mechanisms, such as pulleys or gears, are required to obtain the necessary lower speed, the additional power losses could reduce the efficiency of the system to a value lower than that provided by a direct-drive lower-speed motor.

A definite relationship exists between the rated speed (1/min) and the efficiency of a polyphase induction motor, i.e., the lower the rated speed, the lower is the efficiency, for slip is a measure of the losses in the rotor winding.(Slip of an induction motor is the difference between synchronous speed and operating speed). Slip, expressed in percent, is the difference in speeds divided by the synchronous speed and multiplied by 100. Therefore, Design N cage-induction motors having a slip at full-load of less than 5 percent are more efficient than motors having a higher slip and should be used when permitted by the application.

For loads such as pumps, fans and air compressors, it may be possible to make a significant saving in energy by utilizing a multispeed motor or by using a variable frequency drive (VFD). However, it should be noted that the efficiency of a multispeed motor at each operating speed is somewhat lower than that of a single-speed motor having a comparable rating. Single-winding (Dahlander), multispeed motors are generally more efficient than two-winding, multispeed motors.

Motors which operate continuously or for long periods of time provide a significant opportunity for reducing energy consumption. Examples of such applications are processing machinery, air moving equipment, pumps, and many types of industrial equipment.

While many motors are operated continuously, some motors are used for very short periods of time and for a very low total number of hours per year. Examples of such applications are valve motors, dam gate operators, industrial door openers, fire pumps and sewage pumps. In these instances, a change in motor efficiency would not substantially change the total energy cost since very little total energy is involved and may decrease the required performance.

A modest increase of a few percentage points in motor efficiency can represent a rather significant decrease in percentage of motor losses. For example, for the same output, an increase in efficiency from 75 to 78.9 percent, from 85 to 87.6 percent, or from 90 to 91.8 percent represents a 20 percent decrease in losses in each case.

As efficiency typically increases with the size of the motor, high-voltage machines with output powers well exceeding 1 MW usually have an efficiency above 95%.

NOTE While an electric motor's output power increases with the square of it's size the permissible heat dissipation increases almost linearly. Therefore, a higher efficiency is an inevitable precondition for the design of larger motors.

5.1 Motor losses

An electric motor converts electrical energy into mechanical energy and in so doing incurs losses which are generally described as follows:

a) Electrical (stator and rotor) losses (vary with load) – Current flowing through the motor windings produces losses which are proportional to the current squared times the winding resistance (I^2R). Rotor losses also increase with slip.
b) Iron (core) losses (essentially independent of load) – These losses are confined mainly to the laminated core of the stator and to a lesser degree the rotor. The magnetic field, essential to the production of torque in the motor, causes hysteresis and eddy current losses.

c) Mechanical (friction and windage) losses (essentially independent of load) – Mechanical losses occur in the bearings, fans, and seals of the motor. These losses are generally small in IP4x and IP5x slow speed motors, but may be appreciable in large, high-speed or totally-enclosed IP6x motors.
d) Additional load losses (stray load losses) –The additional fundamental and high-frequency losses in the iron; strand and circulating-current losses in the stator winding; and harmonic losses in the rotor conductors under load. These losses are assumed to be proportional to the torque squared.

Listed below (table 1) are the motor loss components, with the typical percent of the total motor losses they represent, and the design and construction factors which influence their magnitude.

	Typical percent of losses 4-pole motors	**Factors affecting these losses**
Stator losses	30 to 50	Stator conductor size and material.
Rotor losses	20 to 25	Rotor conductor size and material.
Core losses	20 to 25	Type and quantity of magnetic material.
Additional load losses	5 to 15	Primarily manufacturing and design methods.
Friction and windage	5 to 10	Selection/design of fan and bearings.

Table 1 Loss distribution in three-phase, 4-pole, cage-induction electric motors

In general, by increasing the active material in the motor, i.e., the type and volume of conductors and magnetic materials, the losses can be reduced.

5.2 Additional motor-losses when operated on a frequency converter

Harmonics of voltage and current in a cage-induction motor supplied from a frequency-converter cause additional iron and I^2R winding losses in the stator and the rotor. The total value of these additional losses is essentially independent of load. These additional losses decrease with increasing switching frequency in the converter.

In adverse circumstances the additional losses in the motor caused by the frequency converter can increase the total motor losses up to 15…20% compared to grid operation.

For details see IEC 60034-17 and IEC 60034-25.

5.3 Motors for higher efficiency classes

It is expected that advanced technologies will enable manufacturers to design motors for higher efficiencies than IE3 with mechanical dimensions (flanges, shaft heights etc.) compatible to existing motors of lower efficiency classes (for example EN 50347, NEMA MG1 and other local standards). These motors usually require power electronics (frequency converters) to operate.

Losses in the rotor are almost eliminated by using synchronous motors without field winding.
In Annex A, this guide proposes a super-premium efficiency-class IE4 which is specifically targeted at such motors (although the efficiency class IE4 as such is not limited to specific motors).

Permanent-magnet (PMSM) and reluctance (RSM) synchronous-motors are already developed and to some extent commercially available. PMSM usually have some inherent reluctance torque and RSM can be PM enforced thus hybrids are possible.
Depending on the amount of magnet material used, a PMSM can have a higher power factor than an induction motor thus improving efficiency in the distribution network and in the frequency converter. These motors however require a frequency converter and a rotor position sensor (encoder) (unless an encoder-less control algorithm is used in the converter) for proper operation.

A simpler motor control with block-commutated voltage of low switching frequency is also commonly used in small-size and/or high-speed motors ("brushless-DC" or "electronically commutated (EC) motors)"). The main disadvantage is the additional losses due to parasitic harmonic voltages and currents. The improvement in efficiency over asynchronous motors is less compared to the improvement of PWM (pulse-width modulation) controlled permanent-magnet or reluctance synchronous motors.

Another synchronous motor design features both permanent-magnets and a cage. It can therefore be used for on-line starting (line-start, permanent-magnet, synchronous-motors "LSPM"). These motors do not necessarily need a frequency converter for operation. However their starting performance is rather poor with torque ripple and noise and considerable restrictions on the permissible load torque and load inertia. They need to be closely matched to the application and cannot be used as general-purpose machines.

NOTE It is envisaged to expand the scope of IEC 60034-30 and amend it with this Annex A (as normative) when more experience with synchronous motors in standard-applications becomes available.

5.4 Variations in motor losses

All manufactured products are subject to tolerances associated with materials and manufacturing methods. No two products will perform exactly the same, even though they are of the same design and produced on the same assembly line.

This is also true for electric motors. Product tolerances in materials, such as steel used for laminations in the stator and rotor cores, will lead to variations in magnetic properties and ultimately affect iron losses and therefore motor efficiency. Using a tested 7,5 kW motor as an example, a 10 percent increase in iron loss (300 to 330 watts), which is within the tolerance offered by steel suppliers, would increase total motor losses from 946 to 976 watts and reduce efficiency from 88,8 (IE2) to 88,5 (IE1) percent.

Variations also occur as the result of manufacturing process limitations. There is an economic limit to the practical dimensional tolerances on motor parts. Combinations of mating parts contribute to dimensional variations, such as the size of the air gap, which cause variations in additional load loss and hence motor efficiency.

In addition, there are uncertainties caused by manufacturing processes and testing procedures.

Thus in forecasting the efficiency of a given motor, one can speak of the *rated* efficiency as defined by the manufacturer (which should be equivalent to the *average* efficiency of a large population of motors) and above or equal to the required *nominal* efficiency of the rated efficiency class (in accordance to IEC 60034-30).

The actual efficiency at rated load of any individual motor, when operating at rated voltage and frequency, can be lower than the *rated* efficiency but not less than *rated* efficiency minus the tolerance of the efficiency according to IEC 60034-1. This is the level reached when both raw materials and manufacturing processes are at the least favourable end of their specified tolerances.

The *rated* efficiency should be used in estimating the power required to supply a number of motors. The *minimum* efficiency (rated minus tolerance) permits the motor user the assurance of having received the specified level of performance.

5.5 Part load efficiency

Three-phase cage motors offer fairly constant efficiencies over a wide range of partial loads as indicated by Fig. 3

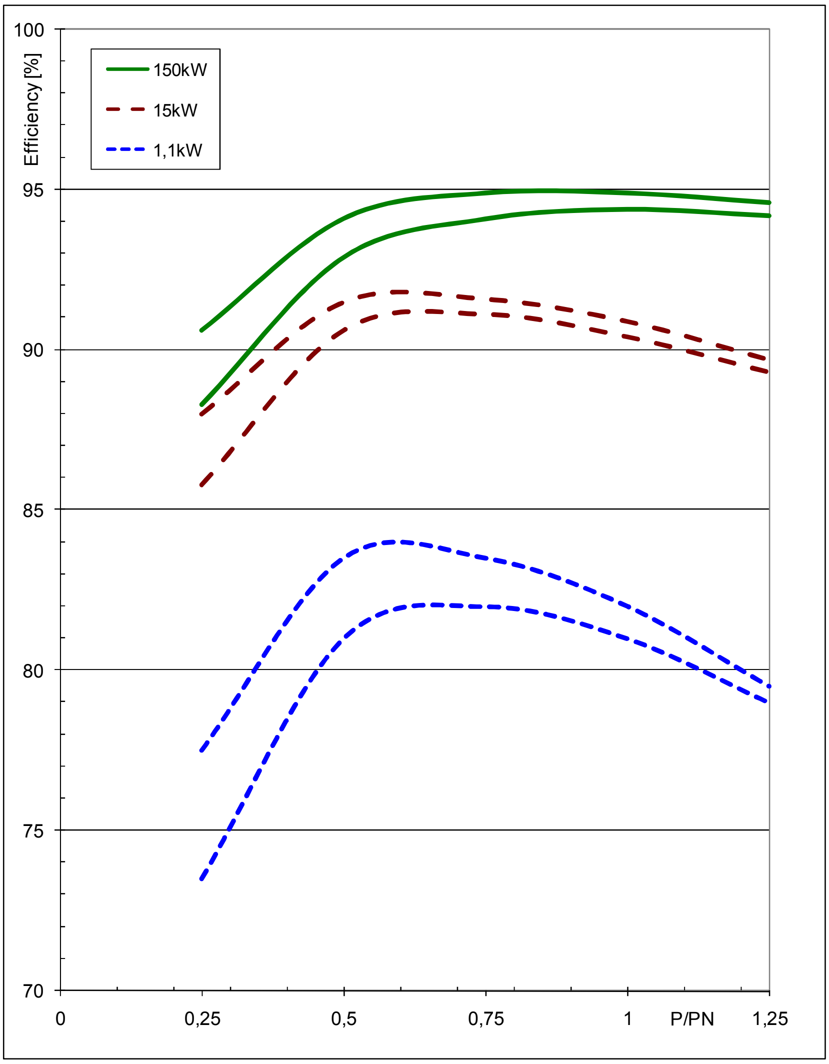

Figure 3 Typical efficiency versus load curve bands for 2- and 4-pole three-phase, cage-induction motors

When the efficiency for rated load and 3/4 load is given, the following formula may be used to compute a good approximation of the efficiency at any other partial load:

$$\nu_L = \frac{\left(\frac{1}{\eta_{100}} - 1\right) - 0.75 \cdot \left(\frac{1}{\eta_{75}} - 1\right)}{0.4375}$$

$$\nu_0 = \left(\frac{1}{\eta_{100}} - 1\right) - \nu_L$$

$$\eta_p = \frac{1}{1 + \frac{\nu_0}{p} + \nu_L \cdot p}$$

with:

η_{100} = Efficiency at rated load (from 0...1 with 1 equals 100%)
η_{75} = Efficiency at 3/4 load (from 0...1 with 1 equals 100%)
ν_L, ν_0 = Intermediate results
p = Desired power (relative to rated load, i.e. from 0...1...overload)
η_p = Resulting efficiency (from 0...1 with 1 equals 100%)

5.6 Efficiency testing methods

There are a number of test methods for determining motor efficiency. Standard methods for testing induction machines are internationally defined in IEC 60034-2-1, which recognizes several methods for determining motor efficiency, each of which has certain advantages as to accuracy, cost, and ease of testing, depending primarily on motor rating. Some of the methods in IEC 60034-2-1 are harmonized with national standards such as CSA C390 and IEEE 112.

The residual-loss method in IEC 60034-2-1 is a defined calculation procedure for segregating the various types of losses from the raw data and smoothing the additional (stray-) load loss by linear regression analysis. This can reduce the effect of errors introduced from making measurements over the range of loads from 25 percent to approximately 150 percent of rated load. It also adjusts the tested ambient temperature to 25°C to reduce variation due to different testing environments.

The common practice for obtaining the raw data for 0,75 to 370 kW is to test the motor with a load machine and a torque meter and to carefully measure the power input and output to determine loss components and thus efficiency.

Adherence to laboratory quality control standards through a national laboratory accreditation program can further assist in minimizing variations in results which occur when a motor is tested at different facilities.

Even with the use of a consistent and accurate efficiency test method, variations in results for the same motor do occur, primarily due to test equipment and instrument characteristics, and in the case of non-automated testing, personnel factors.

5.7 Power Factor

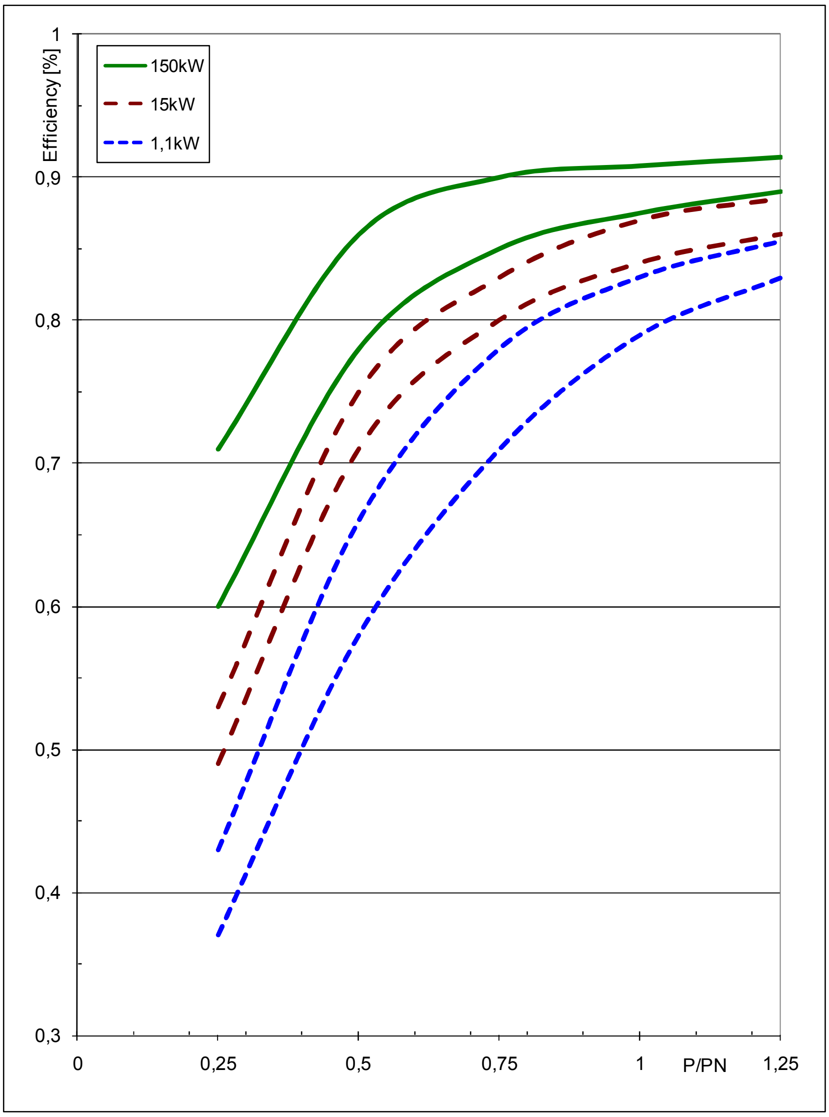

Figure 4 Typical power factor versus load curve bands for 2- and 4-pole three-phase, cage-induction motors

The total motor load in a facility is usually a major factor in determining the system power factor. Low system power factor results in increased losses in the distribution system. Induction motors inherently cause a lagging system power factor.
The power factor of an induction motor decreases as the load decreases.
Rated-load power factor increases with an increase in the power rating of the motor. A number of induction motors, all operating at light load, can cause the electrical system to have a low power factor. The power factor of induction motors at rated load is lower for low-speed motors than for high-speed motors.

A small increase in voltage (less than 10 percent) above rated voltage will decrease the power factor, and a small decrease in voltage (less than 10 percent) below rated voltage will improve the power factor of an induction motor. However, other performance characteristics may be adversely affected by such a change in voltage and operation as close as possible to the rating-plate voltage and power rating is recommended.

An analysis of the electrical system will indicate whether an improvement in the power factor is needed and whether capacitors, synchronous motors, or other corrective measures should be used.

When power-factor-correction capacitors are used to improve power factor of the electrical system they should be carefully selected and applied to avoid unsafe operating conditions. It is recommended that the system designer be consulted for the proper value of corrective capacitance.

5.8 Matching motors and variable speed drives

The addition of an variable frequency controller adds considerable potential for improved energy efficiency in many electric motor systems. The additional costs of the VFD (typically larger than the higher efficiency motor) and some additional losses (which depends upon size and quality typically 2...5% at nominal torque and speed and 10...30% at 25% torque and speed) require a careful analysis of the application.

The first group of applications is pumps, fans and similar with changing loads where torque increases nearly by the square of the rotating speed of the motor. The electric input power of the motor will increase with the third power of speed when the flow volume in closed ducts and pipes is controlled with dampers and throttles only. The VFD can adjust the electric power input smoothly and continuously to the required flow volume and the losses are reduced accordingly. Traditional load control with multi-speed motors or parallel operated multi-motor schemes are to be considered if they can do the job with lower costs and fewer losses. The cost benefit of a VFD is high because a greater energy efficiency improvement is possible.

The second group of applications are conveyors, escalators, hoists and similar where the torque is more or less independent from speed. The VFD can continuously adjust the speed from almost standstill to full speed without steps and can thus minimize the needed power. The cost and efficiency benefits are smaller compared to the first group of applications because the change of input power is linear with the speed.

The third group of applications includes those which have minimal changes in load and speed but can benefit from a VFD in other ways like soft starting and stopping or the requirement of a high starting torque. The main benefit is not in energy efficiency improvements but in less wear of the machinery involved. There are other technical solutions for soft-starting available which require less cost. However, compared to soft-starting with a variable frequency control, these methods do not save energy.

In some applications, motors are oversized and continuously run at part-load (for example 50% or below). Even though a VFD can improve energy efficiency by reducing the input voltage to the motor, a better sizing of the motor for the necessary load would be more cost effective and save even more energy.

Unless additional sinusoidal filters are used, motors operated on a variable frequency drive will be subject to voltage spikes significantly higher compared to grid operation. Today, most new industrial electric motors have an insulation system that can handle these voltages without problems. When retrofitting older motors in existing applications with VFDs, the manufacturer should be contacted. Also it is important to determine the maximum safe operating speed of the motor in case the grid frequency (50 or 60 Hz) shall be exceeded significantly with a VFD. Such information is normally available in catalogues or the product documentation (manuals).

The VFD has to be selected and programmed based on a clear knowledge of the typical operating conditions listed below. It is important to match the performance of the VFD closely with the required load profile and the electric properties of the motor in order to achieve the full benefit of the VFD.

- Torques and speeds required by the driven machine;
- Any motor power derating due to the air-cooling method (self-ventilated or forced ventilation)

5.9 Motors rated for 50 Hz and 60 Hz

As the utilization and size of motors is actually related to torque rather than power the theoretical output power increases linearly with speed, i.e. by 20% from 50 Hz to 60 Hz.

I^2R winding-losses are dominant especially in small and medium sized induction motors. These losses basically remain constant at both 50 Hz and 60 Hz as long as the torque is kept constant. Although windage, friction and iron losses increase with frequency, these losses typically play a minor role in motors with four or more poles. Therefore, at 60 Hz, the losses increase less than the 20% output-power increase compared to 50 Hz and the efficiency improves.

In practice, both 60 Hz and 50 Hz output power designations conform to the standard power levels according to IEC 60072. Therefore, an increased rating of motor power by 20% is not always possible. However the general advantage of 60 Hz still applies if the motor design is optimized for the respective supply frequency rather than just rerated.

The difference in efficiency between 50 Hz and 60 Hz also varies with the number of poles and the size of the motor. In general, the 60 Hz efficiency of three-phase, cage-induction motors in the output power range from 0,75 kW up to 370 kW is about 2,5 to 0,5 points greater when compared to the 50 Hz efficiency. Only large 2-pole motors may have a slightly lower efficiency at 60 Hz due to their higher share of windage and friction losses.

When motors are rated for operation on either 50 Hz or 60 Hz with nearly the same magnetic flux and nearly the same <u>torque</u> (i.e. 20% more power at 60 Hz), for example 400 V / 50 Hz / 3,0 kW and 460 V / 60 Hz / 3,7 kW, the efficiency at 60 Hz is generally higher than at 50 Hz (see Figure 5).

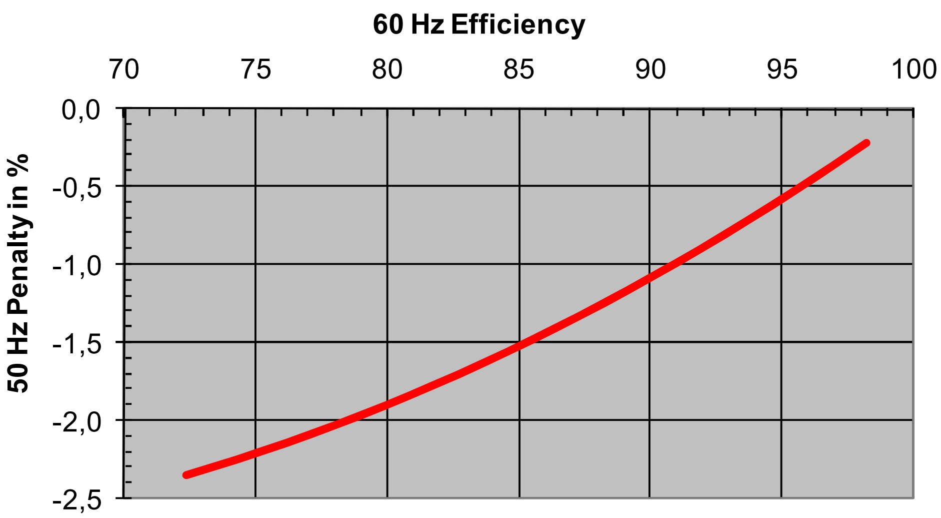

Figure 5 Typical reduction of energy efficiency in %-points for 4-pole, low-voltage motors between 50 and 60 Hz when compared at the same torque (60 Hz power 20% increased)

Alternately, when motors are rated for operation on either 50 Hz or 60 Hz with nearly the same magnetic flux and the same <u>power</u> (i.e. 20% reduced torque at 60 Hz), for example 400 V / 50 Hz / 5,5 kW and 460 V / 60 Hz / 5,5 kW, the efficiency at 60 Hz is always higher because the utilization of the motor is reduced (see Figure 6).

Figure 6 Typical reduction of energy efficiency in %-points for 4-pole, low-voltage motors between 50 and 60 Hz when compared at the same power (60 Hz torque 20% reduced)

For these reasons the limit curves in IEC 60034-30 of the different efficiency classes (IE1, IE2, IE3) are generally higher for 60 Hz motors than for 50 Hz motors.

5.10 Motors rated for different voltages or a voltage range

A change in efficiency as a function of voltage is an inherent characteristic of motors. Operation of the motor at voltages substantially different from rated voltage will result in a change in motor efficiency and heating.
Typically the efficiency of small motors suffers more from voltage deviation than that of larger motors.

5.11 Motors rated for operation at frequencies other than 50/60 Hz

Motors rated for operation at frequencies other than grid frequency (50 or 60 Hz) are not classified in efficiency classes according to IEC 60034-30.
The efficiency class IE4 as defined in Annex A of this document is the only efficiency class applicable to such motors.

5.12 Frequency Converter Efficiency

Frequency converters generally have a high level of energy-efficiency. As with motors, their efficiency drops at partial load (see Figure 7).

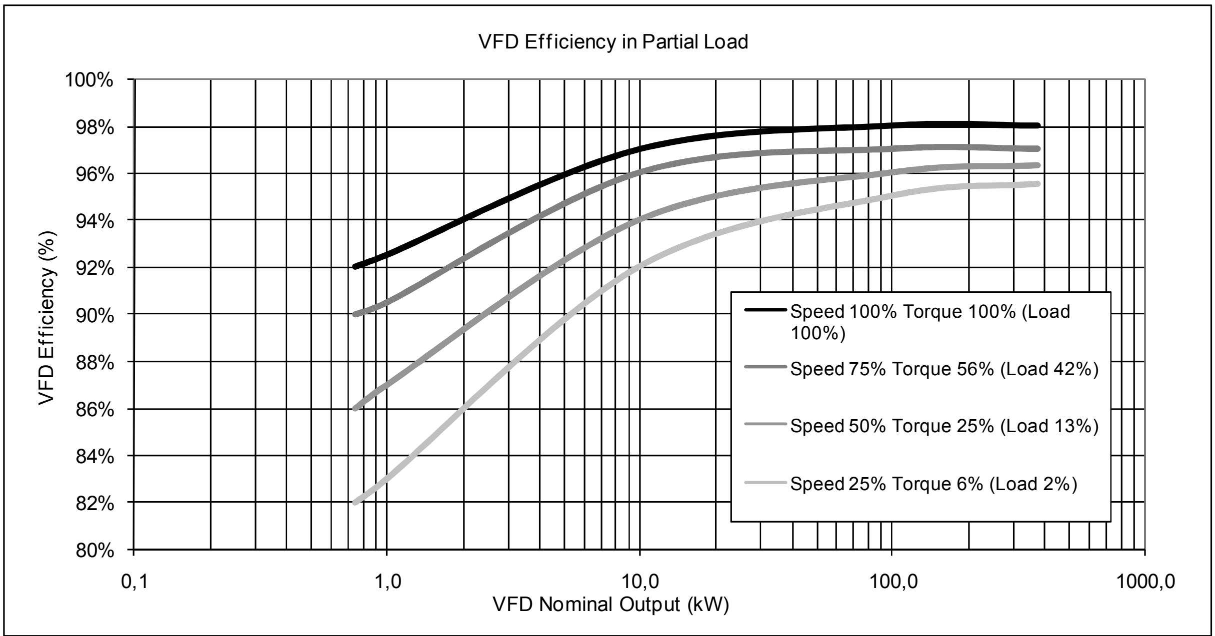

Figure 7 Typical efficiency of indirect three-phase voltage source type converters with a passive front-end

Table 2 gives the frequency converter loss components for the most common industrial converter type (low voltage indirect frequency converters of the voltage source type with uncontrolled three-phase diode rectifiers as line side converter) in the output power range from 1 to 100 kW:

	Typical percent of losses for passive front-end converters	**Factors affecting these losses**
Switching losses (output stage)	30 to 50	Motor-current and switching-frequency.
Line-rectifier losses	20 to 25	Line-current (nearly proportional to motor power).
Forward losses (output stage)	15 to 20	Motor current.
Internal control circuit losses (microcontroller, internal power supply, display, keyboard, bus-communication, digital and analogue ins/outs…)	5 to 20	Nearly constant.
Switching losses (line-side converter / active front-end only)	-	Line-current and switching-frequency (nearly proportional to motor power).
Compound losses (line-side converter / active front-end only)	-	Line-current (nearly proportional to motor power).

Table 2 Loss distribution for low-voltage U-converters
A decrease in converter efficiency may lead to a reduced output voltage to the motor. This may prevent the motor from reaching top speed and/or require field weakening operation which will reduce motor efficiency.

5.13 Frequency Converter Power Factor

The power factor of DC-link converters is only dependent on the design of the converter input rectifier. Motor design or motor loading does not influence converter power factor.

Due to the harmonic content of the input current of frequency converters the total power factor λ has to be analysed:

$$PowerFactor\ \lambda = \frac{|ActivePower\ P|}{\mathrm{ApparentPower}\ S}$$

The power factor can be adjusted nearly to unity by using a converter with an active line-side converter (active front-end).

The following typical examples can be given for the most common types of converters for low-voltage motors (indirect converter of the voltage source type with uncontrolled single or three phase diode rectifier as line side converter):

- 1-phase converter: $\lambda \approx 0{,}58$ (for $P_N \approx 0{,}5$ kW)
- 3-phase converter: $\lambda \approx 0{,}64$ (for $P_N \approx 2$ kW)
- 3-phase converter with line-choke: $\lambda \approx 0{,}92$ (for $P_N \approx 2$ kW)
- 3-phase converter with lean DC-link (small DC-cap.): $\lambda \approx 0{,}94$ (for $P_N \approx 1 \ldots 10$ kW)

As frequency converters improve the power factor on the line-side only it is most energy efficient to install the converter as close to the motor as suitable (decentralized installation).

6 Environment

6.1 Starting performance

Energy efficient cage-induction motors are typically built with more active material, i.e. longer core length and/or higher core diameter in order to achieve the higher efficiency. For these reasons the starting performance of energy efficient motors differs somewhat from motors with a lower efficiency.

On average, the locked-rotor current increases by 10 to 15% for motors from one energy efficiency class compared to motors of the next higher class with the same output power. Individually, this difference is depending on the construction principle of the motor and should be checked with the manufacturer when replacing motors in an existing installation. Copper rotor motors typically have a higher locked-rotor current compared to aluminium rotor motors.

Typically, the average pull-up torque of energy efficient motors is also increased by about 10 to 20% per efficiency class for motors of the same rated output power.

Copper rotor motors typically have a lower pull-up torque compared to aluminium rotor motors.

The manufacturer has to ensure by appropriate design measures to meet the starting performance characteristics as defined in IEC 60034-12 (typically Design-N).

6.2 Operating speed and slip

In general, motors with higher efficiency have a higher operating speed i.e. a reduced slip compared to motors of lower efficiency. On average, the slip is reduced by some 20 to 30% per next higher efficiency class for motors of the same rated output power.

Copper rotor motors typically have a smaller slip and a higher operating speed compared to aluminium rotor motors.

6.3 Effects of Variation in Voltage and Frequency

Operation outside of the rated conditions of voltage and frequency may decrease both efficiency and power factor and may adversely affect other performance characteristics. The same condition is true when operating the motor on other than a sine wave of voltage. The effect of a variation in supply voltage, wave-form, or frequency on the motor's efficiency and power factor characteristics depends on the individual motor design.

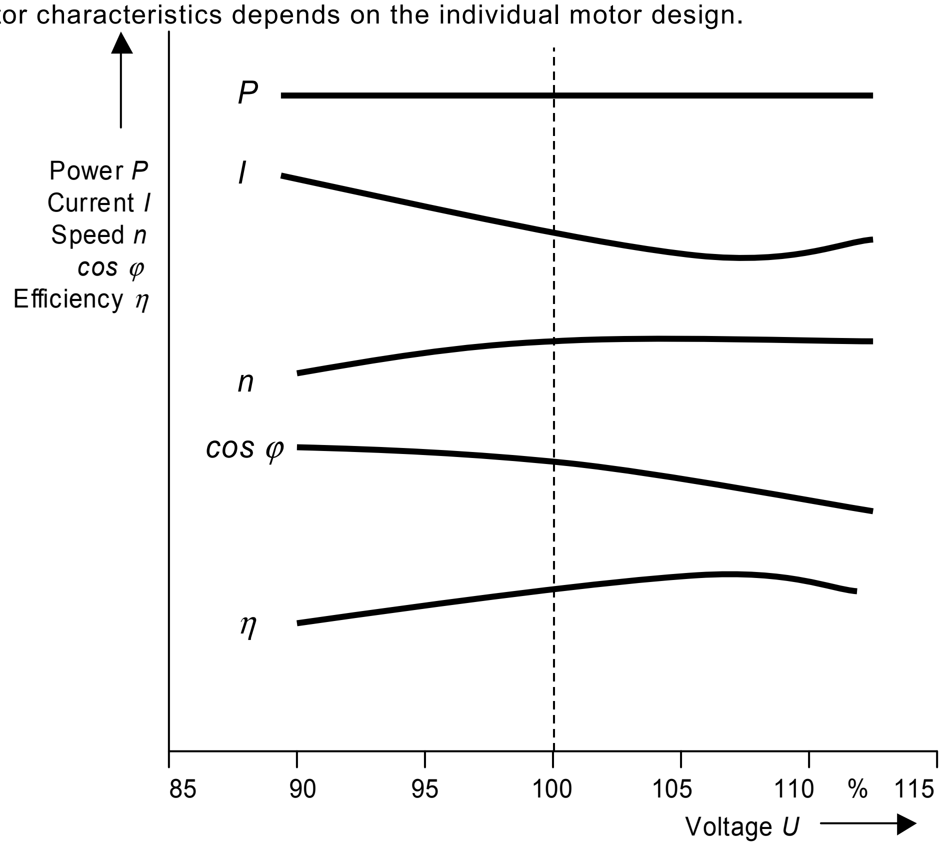

Figure 8 Typical variations of current, speed, power factor and efficiency with voltage for constant output power

For permissible voltage and frequency variations during operation see IEC 60034-1.

6.4 Effects of Voltage Unbalance

A balanced voltage of the three-phase power supply to the motor is essential to the efficient operation of the system. For example, a voltage unbalance of 3.5 percent can increase motor losses by approximately 20 percent. For this reason, single-phase loads taken from a three-phase power supply should be carefully allocated so that the voltage unbalance at the motor terminals will be kept as low as possible.

For details see IEC 60034-26.

6.5 Effects of ambient temperature

The motor rated efficiency is always given for a standard reference ambient temperature of 25 °C (see IEC 60034-2-1). Operation under cooler ambient temperatures will increase efficiency while operation under hotter ambient temperatures will reduce efficiency.

7 Applications

The mechanical output power of standard motors per frame size is not internationally standardized. However regional standards do exist (for example EN 50347 and NEMA MG1) which are widely recognized. It is therefore advantageous for the retrofitting of standard electric motors in existing applications to have energy-efficient motors with the same frame sizes and output powers that won’t require major refurbishments of driven equipments.

When the device being driven by an electric motor is producing a relatively constant and continuous level of useful work, the primary motor selection concern is its rated-load efficiency. However, many applications are cyclic in nature. In these cases specific application techniques can be used to obtain substantial energy savings.

Other applications require intermittent or continuous absorption of energy. Again there are application techniques that will recover a significant percentage of the otherwise wasted energy.

A few of these cases follow to illustrate the technology that is available to the user. The motor manufacturer should be consulted to determine the most effective solution.

7.1 Energy savings by speed control (variable speed drives, VSD)

In many applications, the largest energy savings can be created by varying the speed of the motor according to the application load demand. This is typically done by using a variable speed drive (VSD).

The additional losses in the frequency converter can easily be compensated for by the overall improvement of the application efficiency.

Many pump and fan applications currently involve the control of flow or pressure by means of throttling or bypass devices. Throttling and bypass valves are in effect series and parallel power regulators that perform their function by dissipating the difference between source energy supplied and the desired sink energy.

These losses can be dramatically reduced by controlling the flow rate or pressure by controlling the speed of the pump or fan with a variable speed drive.

7.2 Correct sizing of the motor

Energy efficient motors are specifically useful in applications with a high number of operating hours at greater than ¾ of full load.

In order to avoid significant operating hours with loads below 50% resulting in a lower efficiency the system should be sized according to the required peak-load and starting-torque.

Due to the low temperature utilization of more efficient motors their overload capacity is typically higher when compared to standard motors. Therefore, oversizing the motor for occasional peak-power demands is seldom required and certainly not cost effective.

When a replacement of a standard motor with a high efficiency motor is envisaged in existing applications, the correct power-demand and sizing of the motor should be evaluated.

7.3 Continuous duty application

The achievable energy savings from one energy efficiency class to the next higher are about 15 to 20% reduction in the losses. The payback time of extra investment costs related to high or premium efficient motors can easily be calculated taking the overall motor efficiency and energy cost into account.

The following diagram illustrates the energy savings in percent of the consumed electrical energy of the motor in relation to the rated motor output power when upgrading from a lower IE class to a higher one.

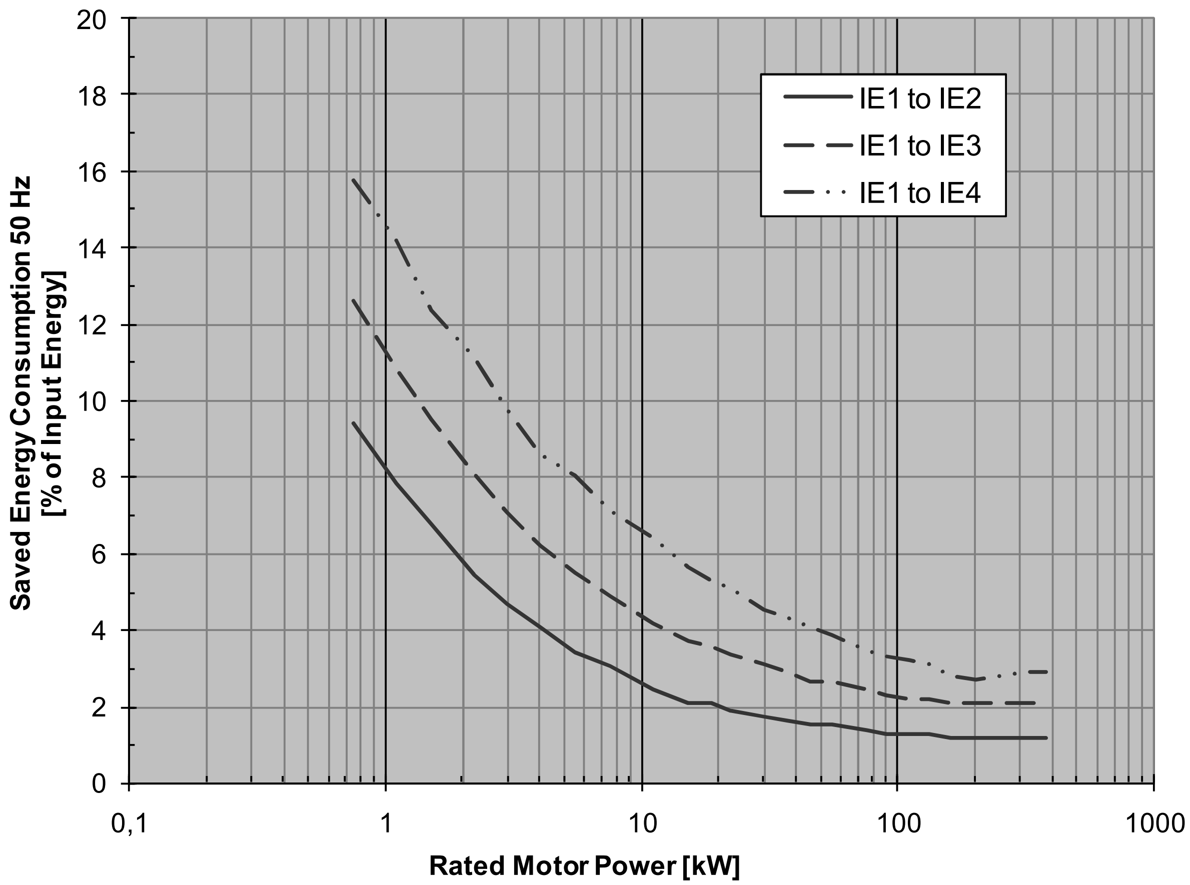

Figure 9 Potential energy savings by improvement of efficiency-classes

7.4 DC-injection braking

An injection of DC into the stator windings will create a retarding torque to bring the motor to a stop. The highest braking torque is typically reached at a speed of 10 to 20% of rated speed.
If full-load current is applied in DC injection braking, the time should be limited to 5 minutes per hour without consulting the motor manufacturer. It is recommended that the motor have over-temperature protection.

During DC injection braking motor heating takes place approximately proportional to the square of the current while applied. This heating (energy dissipation) must be included in the duty cycle analysis for intermittent duty applications.

7.5 Applications involving load cycling

Some applications require running at some load for a period of time followed by a period during which no useful work is being done by the driven machine. In this case energy could be saved by stopping and de-energizing the motor and restarting it at the beginning of the next load period.

When making a decision to stop a motor or to run at no-load a number of factors must be considered; these include motor type, power rating, speed, starting frequency, restrictions on inrush current, power demand charges, and the extra winding stress imposed by repeated accelerations and associated reduction in life expectancy of the EIS.

7.6 Applications involving extended periods of light load operations

A number of methods have been proposed to reduce the voltage applied to the motor in response to the applied load, the purpose of this being to reduce the magnetizing losses during periods when the full torque capability of the motor is not required. Typical of these devices is the power factor controller. The power factor controller is a device that adjusts the voltage applied to the motor to approximate a preset power factor.

These power factor controllers may, for example, be beneficial for use with motors rated less than 3 kW operating for extended periods of light loads where the magnetization losses are a relatively high percentage of the total loss. Care must be exercised in the application of these controllers. Savings are achieved only when the controlled motor is operated for extended periods at light load.

Particular care must be taken when considering their use with other motors rated less than 3 kW. A typical 7,5 kW motor should have idle losses in the order of 4 or 5 percent of the rated output. In this size range the magnetization losses that can be saved may not be equal to the losses caused by the distorted voltage wave form introduced by the power-factor controller.

7.7 Applications involving overhauling loads

Overhauling loads typically result in energy waste if some form of dissipative braking is used. Examples of overhauling loads are: deceleration of high inertia loads, absorption test stands, unwind stands, web process stands, and downhill conveyors. In these cases energy can be saved by the use of regenerative devices.

7.8 Applications where load-torque is increasing with speed (pumps, fans, compressors, ...)

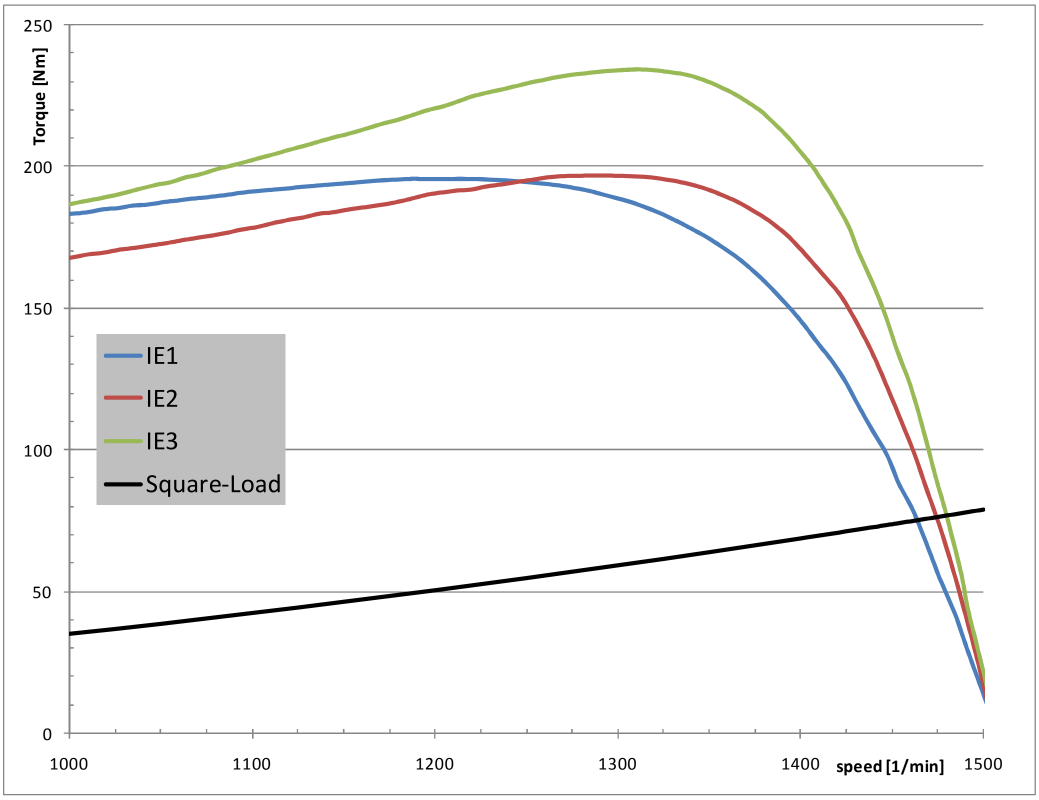

Figure 10 Typical torque versus speed curves for 11kW, 4-pole, three-phase, cage-induction motors and load versus speed curves for -square-loads

As a general rule, high-efficiency cage-induction motors have a lower slip (see table 3), i.e. a higher speed of rotation, than motors of lower efficiency. When the torque of the application is a function of the square of the speed, like in pumps, fans, compressors etc., the increase in speed will lead to an increase in output power (torque) which could in some circumstances defeat the benefits from the improved energy efficiency (see Figure 10).

	eff [%]	n [1/min]	M [Nm]	P_out [kW]	P_in [kW]
IE1	87,6	1464	75,4	11,559	13,195
IE2	89,8	1474	76,4	11,792	13,131
IE3	91,4	1480	77,1	11,948	13,073

Table 3 Example of changing of efficiency, speed and torque demand with energy efficiency class of three 11 kW, 50 Hz motors in the same application

Therefore, in such applications when a motor of lower efficiency is retrofitted by a motor of increased efficiency, the input power should not reduce as much as anticipated when comparing the efficiencies of the two motors.

In some cases the input power of the high-efficiency motor may actually increase compared to the motor of lower efficiency.

7.9 Applications involving frequent starts and stops and/or mechanical braking

High-Efficiency motor designs typically reduce I^2R losses either by a reduced utilization, i.e. by oversizing the motor, and/or by improved conductor material in the rotor (for example die-cast copper instead of aluminium).

However both concepts automatically lead to increased rotor inertia when comparing high-efficiency with lower-efficiency motors of the same output power rating.

In applications where frequent starts and stops are required, the increased rotor-inertia will increase the run-up time and the power-consumption during run-up. It will also reduce the permissible number of starts per hour thereby possibly limiting the application's throughput.

Furthermore, when braking is performed by a mechanical braking system, both the wear of the brake disc and the braking-time will increase with rotor inertia.

The run-up losses can be greatly reduced and the permissible number of starts per hour can be increased by using a frequency converter to start the motor instead of on-line starting. The general disadvantage of high-efficiency motors in this field of applications however remains.

NOTE A soft-starter will reduce the run-up torques but will not reduce losses nor improve the efficiency.

7.10 Applications involving explosive gas or dust atmospheres

Some design restrictions exist for electric motors for explosive gas or dust atmospheres.

Motors with flameproof enclosures ("d") (according to IEC 60079-1) or type of protection "n" (according to IEC 60079-15) are usually not affected.

Motors with increased safety ("e") (according to IEC 60079-7) could be limited by the requirements on t_E-time, air-gap, startup-current etc. Their energy-efficiency level may be reduced.

Motors constructed for use in explosive dust atmospheres with dust ignition protection by enclosure "t" or "tD" (according to IEC 60079-31 or IEC 61241-1) have additional shaft seals.. Their energy-efficiency level might be reduced.

8 Economy

8.1 Relevance to users

The motor user wants a reliable and cost effective motor system. Initial motor purchase cost is low compared with operating cost during the operation phase. Operating costs of electric motors are generally over 90% of the total cost of ownership (see Figure 11).

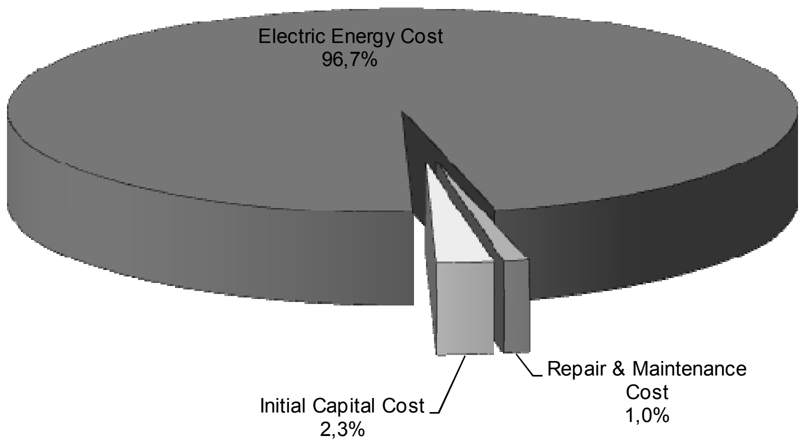

Figure 11 11 kW IE3 motor, 4000 operating hours per year, 15 year life cycle
Source: EuP Lot 11, 2008

Higher efficiency motors cost more because of their higher production quality and additional material used. The additional cost depends on output size and type of motor. Between IE1 and IE2 some 10% to 15%, between IE2 and IE3 another 10% to 15% have to be added to the amount of required active materials (steel, copper). Furthermore, higher quality materials may be necessary.Therefore, the typical price increase could be between 10% to 30% per efficiency class improvement. In comparing motor efficiency not only the increase of efficiency but also the respective power factor has to be taken into account.

Both in the case of replacement and with new installations users are faced with a complex decision for the purchase because it involves the consideration of operating costs together with initial purchase cost for a variety of project possibilities. In the case of replacement also the case of repairing the motor should to be evaluated.

Two methods are generally used for the decision making:

- Simple pay back
- Life cycle cost

8.2 Initial purchase cost

The initial purchase cost consists of planning, installation and the purchase price of the motor and additional equipment like adjustable speed drives (minus rebates, plus taxes).

For every cost comparison a baseline case has to be defined. In countries with MEPS (Minimum Energy Performance Standards) this is the motor with the respective efficiency level, in countries with no mandatory requirements it is the most often used standard motor in a given market. Then a project case has to be defined with higher efficiency motors up to IE3.

The cost of variable speed drives has to be added to the project cost if they are considered to be feasible for the given type of machines and operation.

In case of replacement upon failure no cost for the existing motor has to be taken into account. In case of premature replacement a residual value for the lost operation time can be included with the purchase price calculation.

8.3 Operating cost

The operating cost consists of electricity, maintenance and repair.

The anticipated electricity consumption is calculated based on the following three elements:

- Average annual load factor (for example see figure 12),
- Motor efficiency for this average load factor,
- Annual operating hours.

For fixed speed motors these elements can be estimated easily with fair accuracy. For the calculation of motor systems with variable load and the eventual use of variable speed drives the calculation of the average load factor, the respective hours of operation and the efficiencies of the motor plus the variable speed drive have to be based on a typical load profile. If a relevant measured load profile of existing systems is not available an average profile has to be assumed (example):

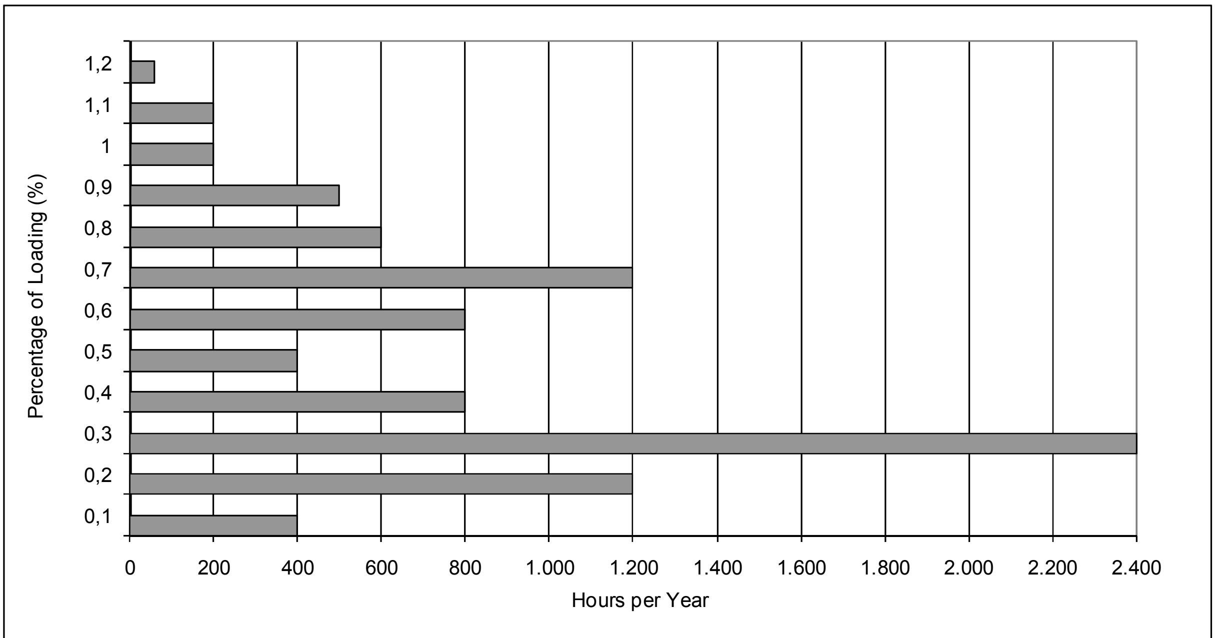

Figure 12 Example of a load factor graph: Fraction of annual operating hours

The operating cost for electricity generally consists of three elements of a tariff or a supply contract with the local utility:

- Energy (kWh) price of consumed electricity (taking day/night, seasonal and other tariff elements into account),
- Paid peak load cost (kW) taking recorded 15 minute peaks,
- Non-corrected power factor (kVA) cost.

Local variations of the above electricity cost elements and structure have to be taken into account as well as discounts, taxes and future price hikes during the anticipated technical lifecycle (how long the machine can typically operate including repairs) of the motor or the application (whatever is less). Fixed costs elements in tariffs are not taken into account because they are not affected by energy efficiency improvements.

Added to the electricity costs are maintenance and repair costs. Their value has to be estimated based on plant experience of cost per operating hour of motors of different output, speed and annual operation.

For a lifecycle cost analysis also the lifetime of the operating costs have to be evaluated. If no data from plant experience in the motor stock are available the following average technical data for lifetime may be used (see table 4):

	Rated motor output (kW)			
	0,75 - 1.1	1,1 - 11	11 - 110	110 - 370
Average lifecycle (years)	10	12	15	20

Table 4 Average lifecycles for electric motors

The actual lifetime depends on annual operating hours, cycles and load factor and motor reliability, maintenance quality and repairs. Because operating cost, especially electricity cost, is by far the dominant element in a cost calculation it should be tested with a sensitivity analysis. One or several elements of the operating costs are varied to check whether the results are robust. Robust results mean that different variants of pay back time or life cycle cost do not change their sequence in the comparison. Often assumptions for annual operating hours are the most critical element and thus should be varied.

8.4 Payback time

The simple pay back method is based on the additional investment for higher efficiency motors (and maybe variable speed drives and other improved equipment) versus lower annual operating cost.

The user has to know the following elements:

- Purchase price of project variants for different efficiency class motors and variable speed drives,
- Annual operating time,

- Cost of electricity.

The user can then calculate operating cost and compare the pay-back time of different proposed project variants. Because pay back times generally are short no estimates of inflation, maintenance labour cost or rise in energy price will be taken into account. The user can then select the solution with the shortest pay-back time.

The user may also have a previously defined maximum pay-back time in his plant which is usually between 2 and 5 years. This period is considerably shorter than the expected lifetime of the motor system. It means that after a short pay-back time the motor continues to run until the end of its technical lifetime free of cost for the added investment. The motor generates in this phase a profit with a "golden end".

8.5 Life cycle cost

In the life cycle cost analysis the summation of the costs of all elements in three phases for different project variants are compared with the baseline:

- Initial purchase (or repair), planning and installation cost,
- Use-phase with operation cost (energy, maintenance and repair),
- End-of-life phase with removal and recycling cost.

For accurate calculation a discounted cash flow analysis has to be made taking interest rates and inflation rates into account. The user has to know the purchase prices of different efficiency class motors and variable speed drives, the annual operating time, the cost of electricity, and also the expected duration of the lifetime and the average cost of maintenance and repair.

The cost of end-of-life is usually neglected in the calculation because recycling of the material of the motor pays for eventual cost of dismantling and transport.

The user can select the project variant with the least life cycle cost. The least life cycle cost is the best choice for the user. In larger investments they can help to decide on optimum projects.

Recent studies in Europe (EuP 2008: Figure 13) confirm that new IE3 motors between 1.1 and 110 kW have lower life cycle costs than IE1 or IE2 motors if they have more than 2000 operating hours per year.

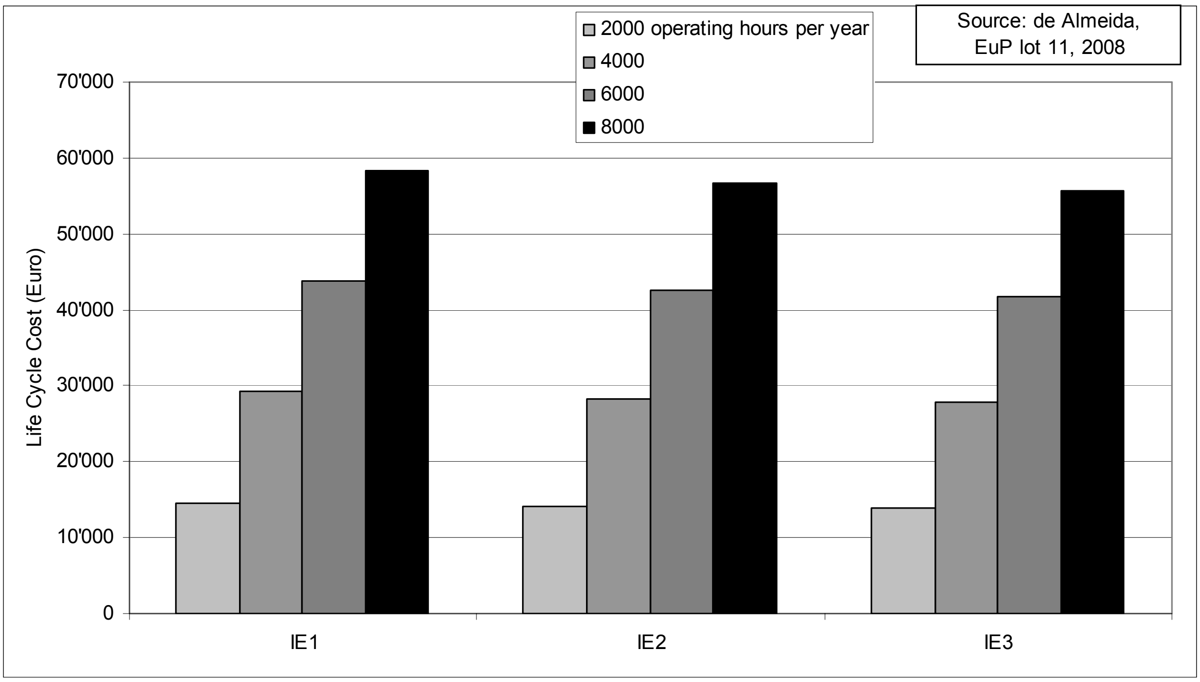

Figure 13 Life cycle cost analysis of 11 kW motor
Source: EuP Lot 11, 2008

In several studies also the environmental impact of high efficiency motors and variable drives have been studied. The additional material used in the production of the more energy efficient equipment is reflected in higher purchase price. The studies confirm that if the life cycle cost is lower for higher efficiency motors this is also true when considering the environmental impact.

9 Maintenance

The electric motor generally needs little maintenance, therefore proper maintenance is often forgotten. There are a number of common abnormalities which have an adverse effect on a motor's performance:

a) insufficient ventilation
b) high ambient temperatures
c) mechanical misalignment
d) improper V-belt application
e) improper lubrication
f) excessive moisture
g) contamination
h) sustained overload
i) abnormal voltage
j) extreme voltage unbalance (single-phasing)

Insufficient ventilation or high ambient temperatures result in higher resistance in the winding. On the average, the efficiency of a motor will decay by 0.2 to 1.0 percentage points from room temperature to its operating temperature. Furthermore, excessive temperature rises caused by poor maintenance or misapplication reduces the operating life of the motor and increases energy consumption.
Sometimes additional friction gradually develops within the driven machine. This could be caused by a buildup of dust on a fan, the wearing of parts, misalignment of gears or belts, or insufficient lubrication in the driven machine. These conditions cause the driven machine to become less efficient, which reduces system efficiency and increases energy consumption. To

assure continued efficient operation and long motor life, a regular schedule for maintenance of motors and driven equipment should be established.

Annex A
Super-Premium Efficiency (IE4)

For information purposes the following proposed nominal limits of Super-Premium Efficiency are given. In 60034-30 the terms “Super-Premium” and “IE4” are projected as approximately 15% reduced losses compared to IE3. The exact definition is proposed in this Annex.

The IE4 energy-efficiency class is not limited to three-phase cage-induction motors like the classes IE1, IE2 and IE3 of IEC 60034-30. Instead, IE4 is intended to be used with all types of electrical motors, particularly with converter-fed machines (both cage-induction and other types like permanent-magnet synchronous-motors, etc.).

Since grid frequency and number of poles of converter-fed machines are not directly related to speed, these motors are typically rated for a speed range and classified by torque rather than power. Consequently the limits of IE4 are ranked by torque and given for discrete speed ranges.

NOTE Users should be aware that frequency converters also have an associated efficiency which will reduce the system efficiency (motor plus converter).

NOTE For efficiency determination of converter-fed motors see IEC 60034-2-3.

However, it is neither required to rate the motor for the entire speed range from 801 to 3600 1/min nor for a constant torque rating over the whole rated speed range.

The nominal limits of Super-Premium Efficiency may generally be computed for the rated torque T_N using the following formula:

$$\eta_N = A \cdot \left[\log_{10}\left(\frac{T_N}{1\,\mathrm{Nm}}\right)\right]^3 + B \cdot \left[\log_{10}\left(\frac{T_N}{1\,\mathrm{Nm}}\right)\right]^2 + C \cdot \log_{10}\left(\frac{T_N}{1\,\mathrm{Nm}}\right) + D$$

where A, B, C, D = interpolation coefficients (see table A.1 below).

NOTE The formula and interpolation coefficients were mathematically derived to create a best fitting curve for the desired nominal efficiency limits. They do not have a physical meaning.

The resulting efficiency (%) are rounded to the nearest tenth, i.e. xx,x%.

Nominal IE4-efficiencies for torques greater than 2000 Nm are equal to the limits for 2000 Nm. Nominal IE4-efficiencies for output powers greater than 400 kW are not defined.

When more than one torque and speed (ranges) are rated, the nominal efficiency limits according to this standard should be computed and applied individually for each combination of rated motor torque(s) and rated speed (ranges).

For motors rated by power P_N rather than torque the following formula should be used to determine T_N:

$$T_N = \frac{P_N}{n_N} \cdot \frac{60 \cdot 1000}{2\pi}$$

The resulting torque should be rounded to the nearest value from the R10 series of preferred numbers, see ISO 3.

In order to maintain compatibility with single-speed, line-operated 2-, 4- and 6-pole motors, table A.3 for torque and speed conversion to standard power levels is provided. On this basis table A.4 gives the nominal IE4-efficiency limits for 50 Hz power supply and table A.5 for 60 Hz power supply.

Table A.1 - Interpolation coefficients

IE-Code	Coefficients	from 801 to 1000 1/min max 2000 Nm	from 1001 to 1200 1/min max 2000 Nm	from 1201 to 1500 1/min max 2000 Nm	from 1501 to 1800 1/min max 2000 Nm	from 1801 to 3000 1/min max 1250 Nm	from 3001 to 3600 1/min max 1000 Nm
IE4	A	0,2824	0,1901	0,1846	0,1648	0,2116	0,2227
	B	-3,8439	-2,9242	-2,7433	-2,4976	-2,6695	-2,7262
	C	17,4628	13,6953	12,7473	11,6595	11,3369	11,1625
	D	70,2209	76,1961	77,9565	79,7787	80,8449	81,2267

For simplified use for discrete torque levels the nominal limits from table A.2 may be applied.

Table A.2 - Nominal limits (%) for Super-Premium Efficiency (IE4)

T_N Nm	from 801 to 1000 1/min	from 1001 to 1200 1/min	from 1201 to 1500 1/min	from 1501 to 1800 1/min	from 1801 to 3000 1/min	from 3001 to 3600 1/min
2,5	76,6	81,2	82,6	84,0	84,9	85,3
3,2	78,0	82,3	83,7	85,0	85,9	86,1
4,0	79,4	83,4	84,7	85,9	86,7	87,0
5,0	80,6	84,4	85,6	86,8	87,5	87,8
6,3	81,9	85,4	86,5	87,6	88,3	88,5
8	83,1	86,3	87,4	88,4	89,1	89,2
10	84,1	87,2	88,1	89,1	89,7	89,9
12,5	85,1	88,0	88,9	89,8	90,3	90,5
16	86,2	88,8	89,7	90,5	91,0	91,1
20	87,1	89,5	90,3	91,1	91,5	91,6
25	87,9	90,1	90,9	91,6	92,1	92,1
32	88,7	90,8	91,5	92,2	92,5	92,6
40	89,5	91,4	92,1	92,7	93,0	93,0
50	90,2	92,0	92,6	93,2	93,4	93,4
63	90,8	92,5	93,1	93,6	93,8	93,8
80	91,5	93,0	93,6	94,1	94,2	94,1
100	92,0	93,4	94,0	94,4	94,5	94,4
125	92,5	93,8	94,3	94,8	94,8	94,7
160	93,1	94,2	94,7	95,1	95,1	95,0
200	93,5	94,5	95,0	95,4	95,4	95,2
250	93,9	94,8	95,3	95,6	95,6	95,4
315	94,3	95,1	95,6	95,9	95,8	95,6
400	94,6	95,4	95,8	96,1	96,0	95,7
500	94,9	95,6	96,0	96,3	96,2	95,9
630	95,2	95,8	96,2	96,5	96,3	96,0
800	95,4	96,0	96,4	96,6	96,4	96,1
1000	95,6	96,1	96,5	96,7	96,5	96,2
1250	95,8	96,2	96,6	96,8	96,6	-
1600	96,0	96,3	96,7	96,9	-	-
2000	96,1	96,4	96,8	97,0	-	-
2500	*96,1*	*96,4*	*96,8*	-	-	-
3150	*96,1*	*96,4*	-	-	-	-
4000	*96,1*	-	-	-	-	-

Table A.3 - Standard power in kW associated with Torque and Speed for line-operated motors

T_N Nm	50 Hz 6-pole (from 801 to 1000 1/min)	60 Hz 6-pole (from 1001 to 1200 1/min)	50 Hz 4-pole (from 1201 to 1500 1/min)	60 Hz 4-pole (from 1501 to 1800 1/min)	50 Hz 2-pole (from 1801 to 3000 1/min)	60 Hz 2-pole (from 3001 to 3600 1/min)
2,5	-	-	-	-	0,75	-
3,2	-	-	-	-	-	1,1
4,0	-	-	-	0,75	1,1	1,5
5,0	-	-	0,75	-	1,5	-
6,3	-	0,75	-	1,1	-	2,2
8	0,75	-	1,1	1,5	2,2	-
10	1,1	1,1	1,5	-	3	3,7
12,5	-	1,5	-	2,2	4	-
16	1,5	-	2,2	-	-	5,5
20	2,2	2,2	3	3,7	5,5	7,5
25	-	-	4	-	7,5	-
32	3	3,7	-	5,5	-	11
40	4	-	5,5	7,5	11	15
50	5,5	5,5	7,5	-	15	18,5
63	-	7,5	-	11	18,5	22
80	7,5	-	11	15	22	30
100	-	11	15	18,5	30	37
125	11	15	18,5	22	37	45
160	15	18,5	22	30	45	55
200	18,5	22	30	37	55	75
250	22	30	37	45	75	90
315	30	37	45	55	90	110
400	37	45	55	75	110 / 132	150
500	45	55	75	90	160	185
630	55	75	90	110	200	220 / 250
800	75	90	110	150	250	300
1000	90 / 110	110	132 / 160	185	315	335 / 375
1250	132	150	200	220 / 250	355 / 375	-
1600	160	185	250	300	-	-
2000	200	220 / 250	315	335 / 375	-	-
2500	250	300 / 335	355 / 375	-	-	-
3150	315	375	-	-	-	-
4000	355 / 375	-	-	-	-	-

Table A.4 – Nominal limits for Super-Premium-Efficiency (IE4) for 50 Hz line-operated motors

P_N kW	2-pole 50 Hz	4-pole 50 Hz	6-pole 50 Hz
0,75	84,9	85,6	83,1
1,1	86,7	87,4	84,1
1,5	87,5	88,1	86,2
2,2	89,1	89,7	87,1
3	89,7	90,3	88,7
4	90,3	90,9	89,5
5,5	91,5	92,1	90,2
7,5	92,1	92,6	91,5
11	93,0	93,6	92,5
15	93,4	94,0	93,1
18,5	93,8	94,3	93,5
22	94,2	94,7	93,9
30	94,5	95,0	94,3
37	94,8	95,3	94,6
45	95,1	95,6	94,9
55	95,4	95,8	95,2
75	95,6	96,0	95,4
90	95,8	96,2	95,6
110	96,0	96,4	95,6
132	96,0	96,5	95,8
160	96,2	96,5	96,0
200	96,3	96,6	96,1
250	96,4	96,7	96,1
315	96,5	96,8	96,1
355	96,6	96,8	96,1
375 (400)	96,6	96,8	96,1

Table A.5 – Nominal limits for Super-Premium-Efficiency (IE4) for 60 Hz line-operated motors

P_N kW	2-pole 60 Hz	4-pole 60 Hz	6-pole 60 Hz
0,75	-	85,9	85,4
1,1	86,1	87,6	87,2
1,5	87,0	88,4	88,0
2,2	88,5	89,8	89,5
3,7	89,9	91,1	90,8
5,5	91,1	92,2	92,0
7,5	91,6	92,7	92,5
11	92,6	93,6	93,4
15	93,0	94,1	93,8
18,5	93,4	94,4	94,2
22	93,8	94,8	94,5
30	94,1	95,1	94,8
37	94,4	95,4	95,1
45	94,7	95,6	95,4
55	95,0	95,9	95,6
75	95,2	96,1	95,8
90	95,4	96,3	96,0
110	95,6	96,5	96,1
150	95,7	96,6	96,2
185	95,9	96,7	96,3
220	96,0	96,8	96,4
250	96,0	96,8	96,4
300	96,1	96,9	96,4
335	96,2	97,0	96,4
375	96,2	97,0	96,4

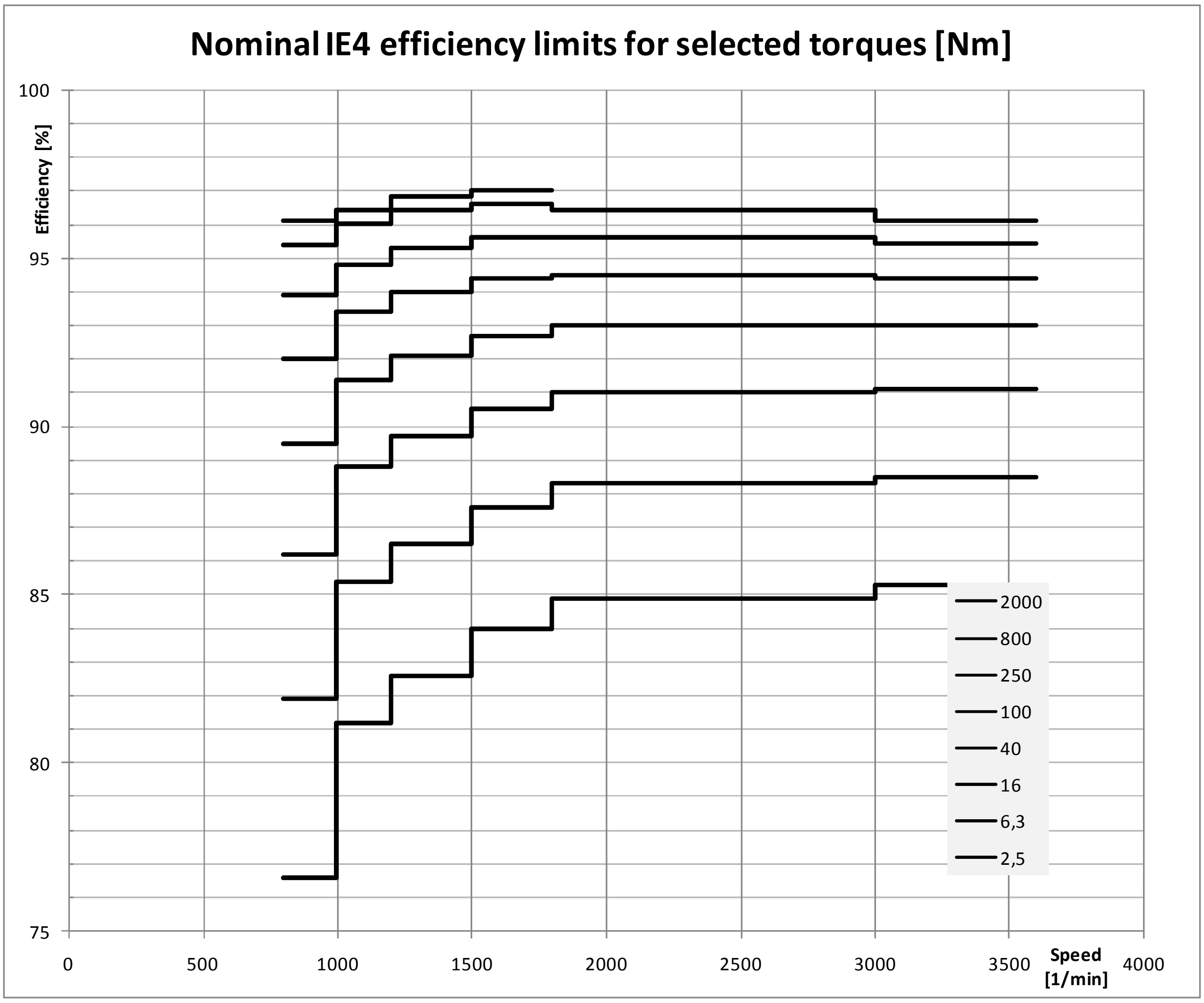

Figure 14 IE4-efficiency limits

Annex B
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